The Influence of Exercise-Induced Arousal on Processes of Memory and Metamemory

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Statement of Sources

I declare that this report is my own original work and that contributions of others have been duly acknowledged.

Ashlee Turner Date

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Abstract

The benefits of exercise for both physical and psychological wellbeing are well established. The present study aimed to further investigate whether exercise is beneficial for memory and metamemory. Forty-one adults were randomly assigned to either exercise prior to encoding (n = 21) or not exercise (n = 20). Participants studied 100 word pairs and predicted the likelihood of recalling and recognising the target word in a memory test. There were no differences in mean number of words recalled between the exercise and control condition. Exercise had an effect on discrimination and confidence for JOLs, where the exercise condition was worse at discriminating between remembered and forgotten items (p = .003, d = 1.08) and had inflated confidence (p = .019, d = 0.78). There was also an effect of exercise on discrimination for FOKs, where those who exercised were worse at discriminating between items they remembered versus forgot (p = .077, d = 0.69). Although this difference did not reach statistical significance, it was a moderate to large effect. There was no effect of exercise on confidence. The data suggests that exercise prior to studying may be detrimental to both memory performance and the ability to accurately judge one's memory.

Despite the known benefits of physical activity for both physical and psychological wellbeing, there are still large proportions of individuals not engaging in sufficient physical activity (Salmon, Owen, Crawford, Bauman, & Sallis, 2003). Physical inactivity is widely accepted as a modifiable risk factor for the prevention of numerous lifestyle diseases, such as cardiovascular disease, diabetes and hypertension (Warburton, Nicol, & Bredin, 2006). Exercise is also known to be beneficial for emotional wellbeing by reducing psychological risk factors such as stress, anxiety and depression (Penedo & Dahn, 2005). It has been established that exercise can be used as a tool for enhancing cognitive efficiency and certain functions underpinning executive control, such as working memory and information processing (Chang, Labbon, Gapin, & Etnier, 2012; Davranche & Audiffren, 2004; Pontiflex, Hillman, Fernhall, Thompson, & Valentini, 2009). It has also been demonstrated that an acute bout of exercise can enhance cognitive functions, such as attention (Côté, Salmela, & Papathanasopoulu), information processing speed (Davranche & Audiffren, 2004), and processes underlying memory (Stroth, Hille, Spitzer, & Reinhardt, 2009).

The effects of exercise on memory have been widely documented. Past literature has focussed more on exercise promoting processes underlying working memory. However, recent research has also argued that the positive effects of exercise also extend to long-term memory (Labban & Etnier, 2011; Stefanidis, 2016). For example, both Labban and Etnier (2011) and Stefanidis (2016) found that exercising prior to learning produced large magnitude effects on subsequent recall memory performance when testing followed a delay. Thus, the aim of the present study was to provide further evidence in support of exercise benefiting constituents of long-term memory.

Memory is a complex process, involving the acquisition, consolidation and retrieval of information. Metacognition, defined as the knowledge one has about their cognition and memory processes and how they use this information for regulating behaviour, has had substantial interest within the memory literature (Koriat, 2007). It has been suggested that being able to effectively monitor your memory (i.e., identify whether you have access to some information in memory) can be indicative of test performance. For example, an individual who is able to effectively monitor their memory to accurately decide whether they can recall some to-be-remembered information is likely to have greater memory accuracy. Thus, given that the accuracy of metacognitive judgements is important for memory, examining and understanding the effects of memory enhancing activities, such as exercise, on metamemory holds practical importance.

Exercise and Cognition

The nature of the relationship between exercise and its benefits to cognition are said to be underpinned by two mechanisms; biological and psychological processes. However, the advantageous nature of these processes are only present under certain conditions of exercise. For example, it is argued that in order to activate the associated biological and psychological mechanisms to a point of enhancing cognition, the exercise needs to be of appropriate intensity and duration (Brisswalter, Collardeuo, & Rene, 2002; Labban & Etnier, 2011).

Psychological explanations suggest that increasing arousal increases the availability of cognitive resources, such as attention, concentration and mental awareness (Brisswalter et al., 2002). Thus by increasing cognitive resources, increased arousal is argued to facilitate greater cognitive performance. The Inverted-

U hypothesis posits that the level of arousal is determined by the intensity of the physical activity. This hypothesis suggests that the benefits to cognition are most pronounced during moderate levels of arousal, induced via moderate intensity exercise (Arent & Landers, 2003). Alternatively, cognitive performance is hindered when arousal levels are high (through high intensity exercise) or low (through no exercise or low intensity exercise; Davey, 1973). Thus, to facilitate the greatest benefits to cognition, exercise should be of a moderate intensity (Labban & Etnier, 2011).

During exercise, catecholamine's such as dopamine, and brain derived neurotrophic factor (BDNF) are released into the body (Gomez-Pinilla, Vaynman, & Ying, 2008). Studies have suggested that BDNF plays a major role in memory formation and storage (Berchtold, Costello, & Cotman, 2010). Similar to psychological accounts, researchers have argued that the intensity and duration of exercise modulate the relationship between activating involved biological mechanisms and cognitive benefits (Brisswalter et al., 2002; Labban & Etnier, 2011). Exercise of a sufficient intensity is essential to release levels of BDNF associated with facilitation of cognitive performance. These conditions are also implicated when considering extending the activation of biological processes when testing follows a delay. Studies have suggested that benefits to cognition are most pronounced under exercise conditions of moderate intensity and duration of 20-minutes (Brisswalter et al., 2002; Chang et al., 2012; Labban & Etnier, 2011; Tomporowski, 2003). Such conditions not only allow for biological mechanisms to be activated, but also ensures that activation is continued for improved cognitive performance following a delay.

Exercise and Memory

Whilst the memory benefits from long-term, chronic engagement with exercise are well documented, interest has developed surrounding the potential improvements to memory via a single session of exercise. Recent findings suggest that benefits to cognition and memory can also be elicited through an acute bout of exercise (Labban & Etnier, 2011; Roig, Nordbrandt, Geertsen, & Nielsen, 2013; Stefanidis, Palmer, Tranent, Sauer, & Fell, 2016).

A number of recent studies have suggested that a single session of exercise exerts a positive influence on constituents of long-term memory (Labban & Etnier, 2011; Stefanidis et al., 2016). Such studies have also argued that exercise has temporal effects on memory performance. Labban and Etnier (2011) observed significant effects of an acute bout of moderate intensity exercise on verbal memory. Improved memory was observed for those who exercise prior to encoding, whereas those who exercised post-encoding had no improvements in their recall (Labban & Etnier, 2011). Stefanidis and colleagues (2016) also observed large magnitude effects of a single bout of moderate intensity exercise on paired-associate memory. Aiming to replicate and substantiate the findings from Labban and Etnier, memory performance was compared between three experimental conditions; exercise prior to encoding, exercise post-encoding or no exercise. Their results provided further support for the argument that exercise exerts temporal effects on memory performance. Recall performance was greater in those who exercised prior to study, compared to the exercise post-study and control conditions. The researchers concluded that exercise prior to learning is superior for improving overall memory performance (Stefanidis et al., 2016).

Conversely, other studies have presented conflicting results, suggesting that physical activity can be detrimental for memory. For example, a recent meta-analytic review suggested that an acute bout of moderate intensity exercise can facilitate response speed in working memory tasks, however it is detrimental to memory accuracy (McMorris, Sproule, Turner, & Hale, 2011). Other researchers have experimentally demonstrated that physical activity before a learning situation can exert negative influences on memory performance (Hope, Lewinski, Dixon, Blocksidge, & Gabbert, 2012). For example, the results from a study conducted by Hope and colleagues (2012) indicated participants who completed a bout of high-intensity physical exertion had a reduced capacity for recalling information about the critical target (compared to those who did no physical exertion). These results suggest that the type of physical activity engaged in (e.g., high-intensity physical exertion versus moderate intensity) influences subsequent memory performance, supporting previous arguments around levels of arousal, biological mechanisms and cognitive performance (Brisswalter et al., 2002; Chang et al., 2012).

Given the arguments for the basis of the Inverted-U hypothesis and biological mechanisms, differential results regarding exercise and memory are likely to be caused by differences in exercise protocols (Labban & Etnier, 2011). For example, previous research has established certain conditions of exercise protocols to facilitate improve cognitive and memory performance. However, research with conflicting results have reported using protocols known to impede performance, such as physical activity of a high-intensity. Other factors have also been identified as undermining the positive effects of exercise on memory, such as engagement in exercise during encoding, dehydration, and fatigue (e.g., exercise durations of 30-minutes or more; Fischer, Hollmann, & De Meirleir, 1991).

Improving memory following exercise requires knowledge of the conditions of exercise that facilitate memory. As previously mentioned, intensity and duration both impact how effective exercise is for enhancing memory. Research has illustrated that the most pronounced improvements occur following exercise protocols of moderate intensity with a duration of 20-minutes. Research has also suggested that the benefits of exercise are only present within a certain timeframe after cessation, after which they begin to decline gradually (Chang et al., 2012). For example, Coles and Tomporowski (2008) found that there was no difference in memory performance between conditions when tested immediately after encoding, however when testing followed a delay, those in the exercise condition recalled significantly more items. Temporal effects of exercise should also be noted, where exercise prior to encoding has the greatest facilitative effect on memory (Labban & Etnier, 2011; Stefanidis et al., 2016). Thus, to promote any effects of exercise on memory, the present study utilised an exercise protocol of moderate intensity with a duration of 20-minutes completed prior to encoding, with a test retention interval of 20-minutes.

Metamemory

Metamemory, as a function of metacognition, is broadly defined as the ability to monitor, control and evaluate one's memory (Nelson, 1996; Chua, Schacter, & Sperling, 2009). Monitoring defines the capacity for observation and subjective assessment of one's memory, and control uses this monitoring output to regulate cognitive processes (Koriat, 2000; Pyc, Rawson, & Aschenbrenner, 2014). Thus, metamemory plays an important role in the processes of memory and learning (Schwartz & Perfect, 2002). Being able to monitor one's memory has considerable importance in everyday life, as accurately monitoring how well newly exposed material is learned is critical for effective regulation of learning (Dunlosky, Rawson, & Middleton, 2005). For example, a student with greater metamemory accuracy will be more effective at monitoring their memory to differentiate the material that they know from that they do not know. Therefore, they will be better equipped for regulating their learning, by concentrating their study efforts on the material they do not know as well. Research has supported this idea, indicating that more accurate monitoring leads to more accurate test performance (Rawson, O'Neil, & Dunlosky, 2011). Thus, understanding the nature of monitoring processes and the factors which influence its effectiveness is essential for both theoretical and practical reasons.

Two types of prospective monitoring tasks are used for assessing metamemory processes: monitoring of learning assessed via judgements of learning (JOLs) and monitoring of retrieval assessed via a feeling-of-knowing judgement (FOK, Hart, 1965). JOLs involve participants making judgements about whether they believe they will be able to recall relevant material on a subsequent test (Nelson & Dunlosky, 1991). For example, in a typical JOL experimental paradigm, after learning a set of word-pairs, participants are asked to predict the likelihood that they will be able to recall the second word from each pair in a subsequent test. The question within the literature is whether these judgements are actually indicative of future recall performance. Studies have indicated that by delaying JOLs, that is, allowing time for the to-be-remembered information to be transferred to long-term memory, these predictions are more indicative of memory performance (Rhodes & Tauber, 2011). Relying on access to information in long-term memory is more diagnostic of subsequent memory performance which in turn suggests greater accuracy of metacognitive judgements (Rhodes & Tauber, 2011). Higher JOL ratings are indicative of higher confidence in future recallability with lower JOL ratings are indicative of poorer confidence in recallability (Koriat, 2007). Several researchers have demonstrated that in the right conditions (i.e., items given higher JOLs are recalled), JOLs are indicative of future recall performance (Koriat, 2008; Pyc et al., 2014).

FOKs are judgements made about the state of believing that some currently unrecallable information will be available later (Reder & Ritter, 1992). In a typical FOK research paradigm, participants are asked to predict the likelihood that they will recognise a piece of information which they previously failed to recall (Sacher, Taconnat, Souchay, & Isingrini, 2009). The accuracy of these judgements is assessed by comparing their FOK predictions against their actual recognition performance. For example, during a study phase, a participant might be presented with the word-pair *"basin-wheat"*. After, they will be presented with basin-_____ and asked to recall the corresponding word. Later, they will be asked to provide an FOK; that is, to predict the likelihood that they will be able to recognise the second word if it was presented with three other alternative options. FOK judgements can be a dichotomous yes or no answer (yes I will be able to recognise the target, or no I will not be able to recognise the target) or a rating on a scale from 0-100% (0 = I will definitely not recognise the target, 100 = I will definitely recognise the target). Following FOK judgements, participants complete a recognition test where they are asked to choose the target word among the distractors (Souchay, Isingrini, & Espagnet, 2000). Higher FOK ratings are indicative of higher confidence in one's memory, whereas lower FOK ratings are indicative lower confidence in one's memory (Koriat, 2007). FOK predictions are argued to be symbolic of recognition performance, when items that are given high FOK ratings are actually recognised (Koriat, 2007).

Exercise and Metamemory. Few studies have examined the effects of a moderate bout of exercise on metamemory regarding JOLs and research is yet to explore how moderate intensity exercise influences FOK predictions.

Several studies have suggested that exercise-induced arousal does not affect the accuracy of JOL predictions. For example, Dutton and Carroll (2001) demonstrated that stepping on the spot did not influence JOL accuracy. Salas, Minakata, and Keleman (2011) observed similar results, suggesting that a bout of walking improved memory performance, but it did not improve the accuracy of JOLs. They argued that this was a product of participants' inability to adjust their judgements to account for their improved memory. However, given the evidence suggesting that exercise intensity modulates benefits to cognitive performance, it is questionable whether walking or stepping on the spot is ample intensity (Brisswalter et al., 2002; Chang et al., 2012). Thus, the effects to metamemory accuracy following exercise protocols that enhance memory were relatively unknown following these studies.

Stefanidis, Palmer, Tranent, Sauer, and Fell (2016) aimed to bridge this gap in the literature, by examining the effects of an acute bout of moderate intensity exercise on memory and metamemory accuracy. The studies aim was twofold: (1) to replicate Labban and Etnier's (2011) results indicating that memory improvements are greater when exercise is completed prior to encoding, and (2) to investigate the effects of moderate intensity exercise on JOL magnitude and accuracy. The study comprised of a moderate intensity exercise protocol completed on a cycle ergometer, and implemented a 30-minute retention interval. Aiming to explore the effects of exercise in relation to memory processes, the study compared recall memory performance on the basis of whether exercise was undertaken prior to encoding, or between encoding and retrieval (Stefanidis, 2016). In the encoding phase, participants leant 90 word pairs. Half of the pairs were unrelated, classified as difficult (e.g., *throw-city*) and the others were associated and classified as easy (e.g., *wool-lamb*). After presentation of the word pairs, participants were asked to provide their JOLs and recall the second word of the pair when presented with the first. The results indicated that the exercise-prior condition recalled significantly more words than both the control (d = .80) and exercise-post condition (d = .61). Furthermore, exercise exerted no influence on participants' ability to distinguish between remembered and forgotten items, thus suggesting that all participants were capable of doing so regardless of condition. However, participants who exercised post-encoding had an inflated belief in their recall ability (i.e., they believed they would recall more items compared to their actual performance). The exercise-prior and control conditions did not have this inflated perception of recall ability, thus their beliefs of their memory were indicative of their actual memory performance. The researchers concluded that individuals do not rely solely on their memory strength when making predictions about the accuracy of their memory, hence suggesting that other processes are involved (Stefanidis, 2016; Koriat, 2007; Koriat & Ma'ayan, 2005).

The current state of the literature has not yet explored how a single session of exercise may affect FOK predictions. Several researchers have argued that JOLs and FOKs rely on different mechanisms for their accuracy (Souchay & Isingrini, 2012), therefore highlighting the need for further investigation into the effects of exercise on FOK accuracy. Son and Metcalfe (2005) proposed the two-stage model to explain JOL accuracy, which argues that JOLs are based not only on the sole mechanism of evaluating one's attempted target retrieval, but also on an assessment of the familiarity with the cue. The mnemonic cues that individuals use to inform their JOLs depend on the type of JOLs being provided. For example, immediate JOLs are based on a cue of encoding fluency whereas delayed JOLs are informed by perceptions of ease of retrieval (Koriat & Ma'ayan, 2005).

Similar to JOLs, it has been argued that FOK accuracy relies on both an attempt to retrieve the relevant information and familiarity with the cue (Hosey, Peynircioğlu, & Rabinovitz, 2009). Koriat (1993) put forward the target accessibility hypothesis, arguing that FOKs are informed by the detection of other partial information related to the target during a memory search. Thus, individuals rely on the amount of and/or the intensity of the partial information available to guide their FOK predictions (Brewer, Marsh, Clark-Foos, & Meeks, 2010). Further research has proposed the utility of other inferential cues, such as contextual information associated with the target (Cook, Marsh, & Hicks, 2006). Several studies have suggested that recollection of contextual information may be a central component to the formation and accuracy of FOK judgements (Brewer et al., 2010). As a result, this indicates that JOLs and FOKs rely on cue familiarity to inform such judgements. However, differential information is obtained for the two types of judgements, where JOLs are informed by cues relating to fluency whereas FOK predictions are informed by cues relating to partial information and recollection (Souchay & Isingrini, 2012).

Theories of Metacognition. The aim of the present study was to identify whether moderate intensity exercise influences the accuracy of metamemory judgements. Two theoretical viewpoints provide differential accounts for how individuals make judgements of their memory capacity. Consequently, these different theoretical perspectives lead to different predictions about how exercise might influence the accuracy of metamemory judgements.

Direct-Access Approach. The direct access approach argues that judgements pertaining to metamemory and the capacity for correct recall or recognition are made based on the actual memory trace for the relevant information (Hart, 1965). It implies that individuals have direct access to their memory trace, and hence use this access to inform their ratings of confidence regarding future test performance (Schwartz, Benjamin, & Bjork, 1997). One implication of this view is that because judgements of metamemory are assumed to be based on the strength of and access to the memory trace, variables which serve to enhance memorability should also influence metamemory predictions. Thus, because exercise has been demonstrated to enhance memory for relevant information, this approach would argue that engaging in exercise should also enhance the accuracy of JOLs and FOKs (Schwartz et al., 1997).

In line with this perspective, Sacher et al. (2009) suggested that the implicit knowledge underpinning FOK predictions is that the better one's memory is for some information, the more accurate their FOK predictions will be. This therefore suggests that individuals do have access to their memory, which facilitates greater knowledge of their memory to inform accurate predictions. A number of studies have supported this argument, indicating that participants who have poorer memory (i.e., perform worse on a memory test), have greater inaccuracy in their FOK predictions (Perrotin, Isingrini, Souchay, Clarys, & Taconnat, 2005; Souchay, Moulin, Clarys, Taconnat, & Isingrini, 2006; Perrotin, Belleville, & Isingrini, 2007).

Inferential Approach. Alternatively, inferential or cue-utilisation approaches argue that individuals do not have direct access to their memory trace. Conversely, they rely on other sources of information which they do have access to apprise their metacognitive judgements (Koriat, 2007; Schwartz et al., 1997). Such information can include perceived fluency during encoding (i.e., belief that easily encoded indicates easily remembered), perceived fluency of recalling an item (i.e., an item that comes to mind quickly is perceived to be correct), or familiarity with a cue that is associated with the to-be-remembered information. This approach suggests that variables which influence memory processes may have a differential effect on metamemory (Schwartz et al., 1997).

Important to note is that the use of an inferential process does not guarantee accuracy of JOLs or FOKs. The accuracy of metamemory predictions relies on the validity of the cues used to inform such judgements (Koriat, 2007). For example, items that are judged as more memorable based on a perceived sense of encoding fluency are likely to be incorrect. This is because perceptions of processing or encoding fluency do not guarantee that the relevant information has been encoded for later retrieval (Koriat & Ma'ayan, 2005). In relation to exercise, the release of endorphins through which enhances feelings of energy may serve to increase feelings of encoding fluency, thus inflating their confidence in their future memory performance. Consequently, relying on perceptions of encoding fluency are likely to undermine metamemory accuracy, based on their lack of validity for actually inferring successful encoding.

Research Aims and Hypotheses

Past research has focussed primarily on two processes underlying memory: retrieval and acquisition. However, research is increasingly working to bridge this gap, by recognising the complex nature of memory, involving acquisition, consolidation and retrieval of information from long term memory, and how these processes can be influenced by arousal enhancing situations, such as exercise. The ways in which arousal can affect other processes such as the ability to monitor and evaluate one's memory and knowledge is also being increasingly recognised in current literature, due to its practical importance in both educational and forensic settings. Thus, the present study aimed to further explore the effects of exercise on memory and processes of metamemory.

Consistent with Labban and Etnier (2011) and Stefanidis et al. (2016), it was predicted that those who exercised prior to encoding would have greater rates of both recall and recognition accuracy, compared to those who did not exercise. With reference to JOLs, it was predicted that those who exercised prior to encoding would not differ in their metamemory accuracy in comparison to the control condition, thus supporting the view that memory strength may not be the only process involved in predicting future memory performance. FOK accuracy was tested against two competing models which would predict that (a) exercise will improve FOK accuracy due to improvements to memory, or (b) exercise will inflate confidence thus reducing FOK accuracy due to use of invalid inferential cues.

Method

Participants

The present study utilised a convenience sample of 41 adults (20 males and 21 females), ranging in age from 18 to 40 years (M = 23.24, SD = 5.61). Participants were recruited from the University of Tasmania's Newnham campus. Students undertaking first year psychology units received one and a half hours' research credit. All other participants were reimbursed 30 dollars for volunteering their time.

Exclusion criteria was based on potential participants' responses on The Adult Pre-Exercise Screening Tool (TASPEST) provided by Exercise and Sports Science

Australia, Fitness Australia and Sports Medicine Australia (Norton & Norton, 2011; see Appendix D). Any condition with the capacity to weaken memory performance; one's ability to engage in moderate intensity exercise; or likely to be aggravated via exercise warranted exclusion from the study. Such conditions included cardiovascular disease, hypertension, uncontrolled diabetes, physical injuries, cognitive impairments and learning disorders. Stage one identifies individuals with a known disease, or signs and symptoms of a disease, suggestive of a higher risk for adverse outcomes following exercise. Any participants who answered 'YES' to any of the seven items in stage one were excluded from the study. Stage two identifies other potential risk factors, asking for information regarding medical history, fitness level, body mass index (BMI) and tobacco use. Those who (a) responded 'NO' to the first seven items, and (b) were classified as 'low risk' (identified by having less than two risk factors), were invited to participate.

Design

The present study utilised a one-way between-groups design, investigating whether completing an acute bout of moderate intensity exercise influenced recall and recognition accuracy, and the accuracy of JOL and FOK predictions.

Materials and Procedure

The total session took approximately one and a half hour to two hours to complete. Participants were randomly allocated to either the exercise or control condition prior to coming in to the lab. Upon arrival, participants were fitted with heart rate monitors below their sternum, worn for the duration of the session. Their heart rate was displayed on a watch monitor that was placed on the desk beside them.

Heart rate was recorded every 5-minutes during the exercise protocol, and at the end of each phase of the study.

Before beginning, participants gave their informed consent and completed a questionnaire whilst remaining seated to get a measure of resting heart rate. The International Physical Activity Questionnaire (I-PAQ) was used to evaluate participant's physical activity levels during the past seven days (Craig et al., 2003; see Appendix E). This was used as an index of physical fitness, due to its ability to have differential effects of exercise on memory (Chang et al., 2012). Participants were asked to think about any activity done via work, home, recreation, exercise and sporting activities.

The first phase of the study was the exercise manipulation. Participants allocated to the exercise condition completed the bout of exercise whilst the control condition watched a 30-minute animal documentary. This documentary was chosen based on its ability to be attentionally engaging without increasing arousal or depleting cognitive resources. After the experimental manipulation, all participants continued onto the study phase. Following the study phase, there was a 20-minute retention interval. This was included because researchers have argued that greater benefits to memory are observed when time is allowed for complete memory consolidation (Roig et al., 2013). Upon completion of the video, all participants commenced the memory testing phase.

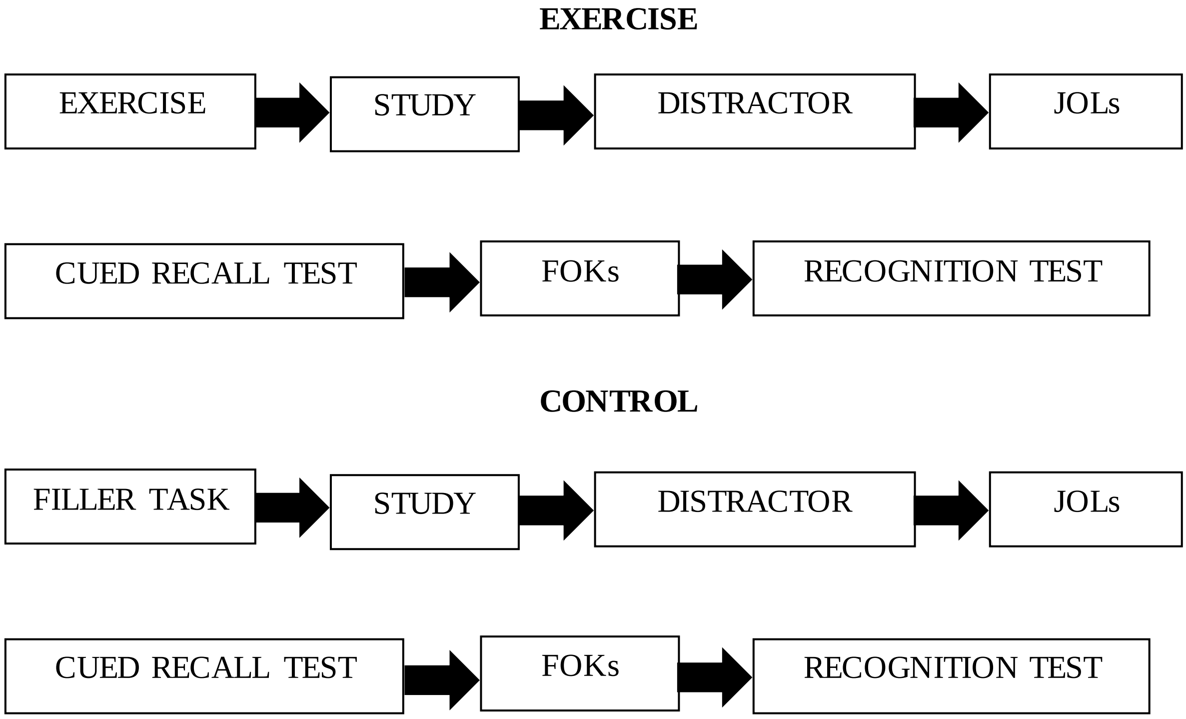

Figure 1. Sequence of tasks for each condition.

Exercise Manipulation. The exercise protocol consisted of a 5-minute warm up, 20-minutes of moderate intensity exercise, and a 5-minute cool down, all completed on a cycle ergometer. The study tracked exercise intensity via two physiological measures: (1) heart rate and (2) Borg's (1988) Rating of Perceived Exertion (RPE) scale. Heart rate was measured throughout the duration of the session and recorded at every 5-minute interval. Moderate intensity is defined by heart rate ranging from 55 to 70% of the participant's maximum heart rate, calculated by subtracting the participants age from 220 (ACSM, 2014; Norton & Norton, 2011). If participants exceeded the target range by approximately 10 beats per minute, they were instructed to adjust the resistance on the cycle ergometer to decrease their heart rate.

Borg's (1988) scale of RPE was used as an additional index of exercise intensity. The RPE scale ranges from 0 (sedentary) to 11 (maximal physical exertion; Borg, 1988). Participants were instructed to pedal at a speed of 60 revolutions per minute (RPM) whilst regulating the resistance of the ergometer until they were working at perceived exertion level of 3-4 (ACSM, 2014). Participants were asked to base their ratings of exertion according to "the feeling of strain and fatigue in their muscles, and alterations in their breathing". Participants were advised that these changes in breathing should not be at a level which undermined their ability to hold a conversation, but should be sufficient enough to detect changes (Borg, 1988; Norton & Norton, 2011). Participants were advised to maintain this intensity for the total 20-minutes, which was monitored and confirmed every 5-minutes.

Memory Task. The memory task was a computerized visual memory task, presented on a 19-inch PC. Participants were presented with 100 English-English word-pairs (see Appendix C). They were instructed to learn the word pairs at their own pace in preparation for a test, requiring them to remember the second word (target) when presented with the first word (cue) of each pair (Koriat, 2008; Koriat & Ma'ayan, 2005). The word-pairs were presented on the screen one at a time until participants prompted the task to continue onto the next word-pair, by pressing the SPACE BAR key. Word-pairs were presented in a randomized order.

The test phase consisted of four stages: delayed JOLs, a recall test, FOKs and a recognition test. In the JOL phase, participants were instructed that they would be presented with the cue word from each word-pair and asked to provide a JOL: that is, give a rating of how certain they felt that they would be able to remember the target word when shown the cue word. Ratings ranged from 0 (*completely uncertain*) to

100 (*completely certain*). Higher ratings were indicative of higher confidence in memory, whereas lower ratings were indicative of lower confidence (Koriat, 2007). During the recall test phase, participants were shown the cue word in a randomized order and asked to recall the target word for each pair. Once providing their answer, participants prompted the computer to continue onto the next word. After completing the recall phase, participants were given the opportunity to take a short break for a few minutes before moving onto the next phase.

In the FOK phase, participants were presented with the cue word and asked to give a rating of how certain they felt that they would be able to recognise the target word if there were four possible options to choose from, ranging from 0-100%. Higher ratings were indicative of higher confidence in memory, whereas lower ratings were indicative of lower confidence (Koriat, 2007). In the recognition test phase, participants were instructed that they would be presented with the cue word and were asked to pick the target word from a list of four alternative choices. For example, when presented with the cue word "*basin*", participants were asked to press the number on the keyboard of the corresponding target word from a list including, "*1. wheat*", "*2. right*", "*3. anger*", and "*4. sleep*". Participants were asked that even if they were unsure of the correct answer, to make their best guess and not skip any questions.

Analysis of Metamemory Accuracy

Assessing confidence-accuracy (CA) relationships has generally been examined via the point-biserial correlation. However, researchers in this area (e.g., Juslin, Olsson, & Winman, 1996) argue that the point-biserial approach provides a limited overview of the CA relationship, therefore suggesting the use of calibration analyses as it provides a more detailed perspective (Sauer, Brewer, Zweck, & Weber, 2010). Thus, the present study conducted calibration analyses to assess the accuracy of JOLs and FOKs, relative to memory performance.

Calibration provides information regarding two independent facets of the CA relationship; resolution and calibration. *Calibration* indexes the degree of association between the subjective (i.e., confidence) and objective probabilities of getting an item correct (Sauer et al., 2010; Palmer, Brewer, Weber, & Nagesh, 2013). For perfect calibration, 100% of all responses given 100% confidence are accurate, 90% of responses given 90% confidence are accurate etc. (see Figure 2 for graphical representation). This information can be presented in multiple ways, via a visual representation and statistical measures. The graphical representation of calibration is constructed by plotting confidence judgements against accuracy, to assess the ideal function of the CA relationship (i.e., optimal calibration) compared to the actual function (Sauer et al., 2010). Statistical measures include the *C statistic*, which gives an indication of the deviation from perfect calibration, ranging from 0 (*perfect calibration*) to 1 (*worst possible calibration*). *O/U* statistics can also be calculated, which indexes individuals' tendency to overestimate or underestimate their memory. Values range from -1 (*complete underconfidence*) to +1 (*complete overconfidence*), with an ideal value of 0 indicating no bias in confidence ratings (Weber & Brewer, 2004).

Another outcome of calibration analyses is a measure of resolution, which indexes the level to which JOLs and FOKs discriminate correct items from incorrect items (Palmer et al., 2013; Yaniv, Yates, & Smith, 1991). This capacity for discrimination is inferred by the Adjusted Normalised Discrimination Index (*ANDI*), with values ranging from 0 (*no discrimination*) to 1 (*perfect discrimination*) (Yaniv et al., 1991).

The present study assessed the accuracy of JOLs and FOKs in two contexts: (1) deviation from optimal confidence-accuracy calibration (as indexed by the *C* statistic and *O/U* statistic), and (2) the ability of JOLs and FOKs to discriminate between items remembered versus items forgotten (as indexed by the *ANDI* value). As noted by Yaniv et al. (1991), these two indices provide conceptually different information of the accuracy of JOLs and FOKs (i.e., good calibration does not necessarily indicate good discrimination and vice versa). Thus, it is important to examine all indices of metamemory accuracy to gain a comprehensive understanding of how exercise influences JOL and FOK accuracy.

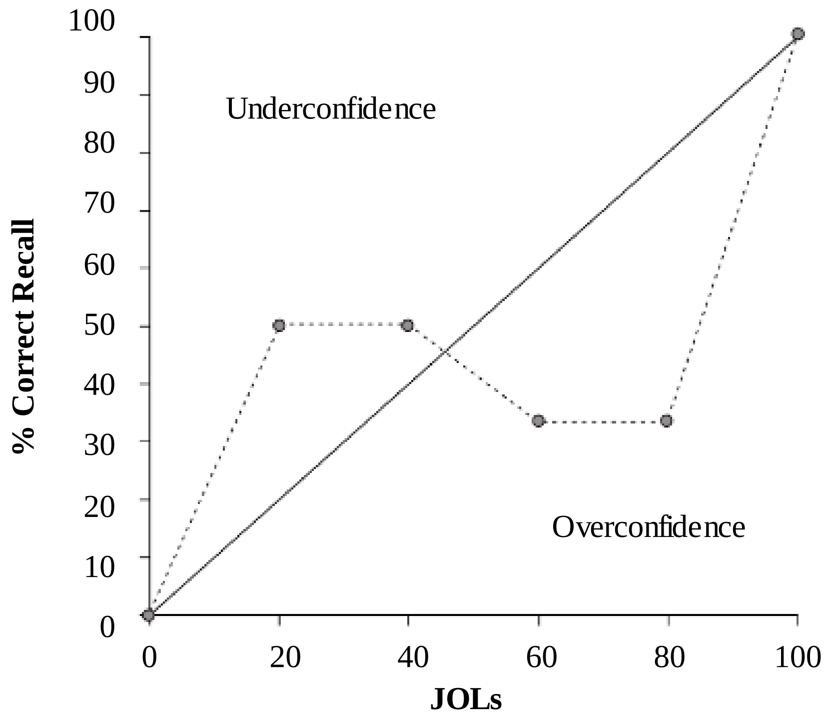

Figure 2. Solid line represents optimal calibration.

Results

The present study employed a one-way between subjects' design with exercise manipulated into two conditions; exercise prior to encoding or no exercise. Independent samples t-tests and chi-square contingency statistics were conducted to examine differences in heart rate, fitness capacity and BMI across conditions to assess the validity of the exercise manipulation and possible moderating factors. A series of independent samples t-tests were conducted to investigate differences in recall and recognition accuracy, along with JOL and FOK magnitude and accuracy. Additionally, one-sample t-tests were used to examine whether *ANDI* and *O/U* values differed significantly from zero, examining JOL and FOK accuracy across the total sample (see Appendix F for data output). Alpha levels were maintained at $\alpha = .05$ and Cohen's *d* effect sizes were interpreted as small (.20), moderate (.50) and large effects (.80; Cohen, 1988).

Data Screening

Data were screened for potential violations of assumptions, including normality and homogeneity of variance. Some of the data were positively skewed, however transformations had no impact on the results. Thus, all analyses were conducted on raw data.

Manipulation Checks

Heart Rate. The exercise manipulation functioned as intended. A number of independent samples-t-tests were conducted to test for differences in heart rate at rest, during study and during testing (means and standard deviations reported in Table 1). First, no significant differences were present in resting heart rate between conditions, $t(39) = -1.85$, $p = .071$, $d = 0.58$, offering initial evidence that fitness capacity did not differ across groups. A moderate effect size does however suggest that there is evidence of slightly higher resting heart rate in the exercise condition. Heart rate was increased in the exercise-prior condition in comparison to the control condition both at the beginning of the study phase, $t(39) = -9.76$, $p < .001$, 95%CI_{diff} [-48.04, -31.55], $d = 3.05$, and at the conclusion of the study phase, $t(39) = -3.73$, $p = .001$, 95%CI_{diff} [-21.97, -6.51], $d = 1.16$.

Table 1

Means and Standard Deviations of Heart Rate at Rest, Start of Study and Post-Study per Condition

	Resting	Start of Study	Post-Study
	M(SD)	*M(SD)*	*M(SD)*
Control (n = 20)	72.65 (10.88)	73.35 (12.10)[a]	74.05 (11.80)[b]
Exercise (n = 21)	78.14 (7.93)	113.14 (13.88)[a]	88.29 (12.63)[b]

Note: Means with corresponding subscripts differ significantly = $p < .05$.

Possible Moderating Factors

Numerous tests were conducted to assess the influence of potential moderating factors, including fitness capacity and BMI. A chi-square analysis of independence was conducted to assess whether fitness capacity differed across conditions. The analysis revealed no significant difference in the proportion of participants of low, moderate and high fitness capacity across conditions, $\chi^2(3) = 3.79$, $p = .286$. An independent samples t-test revealed that BMI did not significantly differ between the exercise (M = 24.13, SD = 3.50) and control condition (M = 22.04, SD = 6.44), t (39) = -1.30, p = .203. This indicates that conditions were functionally equivalent.

Memory Performance

Correct Recall. Exercise prior to study did not enhance recall performance. An independent samples t-test revealed no significant effect of condition of recall performance, t (39) = 1.11, p = .275, 95% CIdiff [-4.78, 16.33], d = 0.35 (see Table 2 for means and standard deviations).

False Recall. Although the focus was on correct recall, analyses were also conducted to assess effects on false recall: that is, the number of responses incorrectly recalled. Analyses indicated that exercise had no influence on level of false recall. An independent samples t-test revealed no significant effect of condition on false recall, t (39) = -1.38, p = .175, 95% CI_{diff} [-14.79, 2.79], d = 0.43 (see Table 2 for means and standard deviations).

Correct Recognition. There was no effect of exercise on recognition memory performance. An independent samples t-test indicated that there was no significant effect of condition on recognition performance, t (39) = 1.09, p = .283, 95% CI_{diff} [-5.18, 17.28], d = 0.34 (see Table 2 for means and standard deviations).

Overall, exercise prior to study decreased accuracy of memory performance. Comparison of the means indicates that the exercise condition recalled less correct words, recalled more incorrect words (i.e., higher level of false recall) and correctly recognised less words. The non-trivial effect sizes (all small to moderate) suggest that the observed results could have reached statistical significance with a sufficiently powered study.

Table 2

Means and Standard Deviations for Correct Recall, False Recall and Correct Recognition per Condition

	Correct Recall	False Recall	Correct Recognition
	M(SD)	*M(SD)*	*M(SD)*
Exercise (n = 21)	11.43 (14.95)	18.00 (15.95)	54.00 (17.35)
Control (n = 20)	17.20 (18.37	12.00 (11.36)	60.05 (18.21)

Metamemory Accuracy

Accuracy of JOLs. The present findings provide further support for previous metamemory literature regarding the accuracy of JOLs (Koriat, 2007; Pyc et al., 2014). JOLs were indicative of recall performance. One-sample t-tests were conducted to analyse the accuracy of JOLs across the total sample. These tests revealed that the *ANDI* value (M = 0.523, SD = 0.29) was significantly different from zero, t (34) = 10.84, p < .001, 95% CI [0.43, 0.62]. This indicates that 52.3% of JOLs discriminated between remembered and forgotten items. A positive *O/U* value (M = 0.15, SD = 0.14) suggests that participants tended to be somewhat overconfident in their JOL predictions, t (40) = 6.98, p < .001, 95% CI [0.11, 0.20].

Effect of Exercise on Magnitude of JOLs. Exercise did not affect the magnitude of JOL predictions. An independent samples t-test indicated that JOL magnitude did not differ significantly between the exercise (*M* = 31.78, *SD* = 18.51) and control condition (*M* = 27.87, *SD* = 18.74), t (39) = -.67, p = .505, 95% CI_{diff} [-15.69, 7.85], d = 0.21.

Effect of Exercise on JOL accuracy. The assumption of homogeneity of variance was violated for all indices of JOL accuracy (Levene's statistic all > 4.5, p < .035), thus equal variances were not assumed.

Exercise prior to study diminished participants' ability to discriminate between items they did and did not remember. An independent samples t-test indicated significant effect of exercise on the ability to differentiate known from unknown items, t (32.08) = 3.28, p = .003, 95% CI_{diff} [.10, .43], d = 1.08 (see Table 3 for means and standard deviations).

Exercise prior to study inflated participant's confidence in their ability to recall items. An independent samples t-test revealed a significant effect of condition on *O/U* values, t (35.95) = -2.45, p = .019, 95% CI_{diff} [-.18, -.02], d = .78 (see Table 3 for means and standard deviations). A higher positive *O/U* value in the exercise condition suggests that exercise increased overconfidence in correct recall ability.

Given the effects on confidence, exercise prior to encoding also influenced greater discrepancies between subjective and actual accuracy. An independent samples t-test revealed a significant effect of condition on calibration, t (32.01) = -2.64, p = .013, CI_{diff} [-.13, -.02], d = 0.79 (see Table 3 for means and standard deviations).

Overall, exercise prior to encoding reduced the accuracy of participants' JOL predictions. The results suggest that exercising prior to encoding reduces the ability for JOLs to distinguish between remembered and forgotten items and leads to greater overconfidence regarding capacity for correct recall. Greater overconfidence indicates that exercise prior to encoding leads to more deviation from optimal calibration of subjective and actual accuracy.

Table 3

Raw O/U, ANDI and Calibration Values for JOLs per Condition

	ANDI	*O/U*	*C*
	M(SD)	*M(SD)*	*M(SD)*
Exercise (n = 21)	.41 (.30)[a]	.20 (.15)[b]	.12 (.11)[c]
Control (n = 20)	.68 (.18)[a]	.10 (.11)[b]	.05 (.06)[c]

Note: Means with corresponding subscripts differ significantly = $p < .05$.

Accuracy of FOKs. In line with the previous literature, FOKs were indicative of recognition accuracy (Costermans, Lories, & Ansay, 1992). One-sample t-tests were conducted to analyse the accuracy of FOKs across the total sample. First, it was revealed that the *ANDI* value (M = .083, SD = .07) was significantly different from zero, t (40) = 7.29, $p < .001$, thus indicating that 8.3% of FOKs distinguished between remembered and forgotten items. Additionally, a negatively biased *O/U* value (M = -.18, SD = .16) suggests that participants were slightly underconfident in their FOK predictions, t (40) = -7.03, $p < .001$.

Effect of Exercise on Magnitude of FOKs. Exercise did not influence the magnitude of FOK judgements. An independent samples t-test indicated that FOK magnitude did not differ significantly between the exercise (*M* = 40.09, SD = 21.15) and the control conditions (*M* = 38.38, *SD* = 20.18), *t* (39) = -.27, *p* = .792, 95% CI_{diff} [-14.78, 11.36], *d* = 0.61.

Effect of Exercise on FOK accuracy. The assumption of homogeneity of variance was violated for analysis of *ANDI* values (Levene's statistic = 5.08, p = .03), thus equal variances were not assumed. Exercise prior to encoding did not affect participants' ability to discriminate between remembered and forgotten items. An independent samples t-test revealed no significant effect of condition on participants' ability to distinguish between known and unknown items, *t* (28.82) = 1.83, *p* = .077, 95% CI_{diff} [-0.01, 0.09], *d* = 0.69. However, a moderate effect size suggests some evidence of an actual effect.

Exercise prior to encoding had no effect on participant's confidence in their ability to recognise items. An independent samples t-test revealed no significant effect of condition on *O/U* values, *t* (39) = -1.19, *p* = .242, 95% CI_{diff} [-0.04, 0.04], *d* = 0.43.

Given no effect on confidence, conditions did not differ in the magnitude of the discrepancies between subjective and actual accuracy. An independent samples t-test indicated no significant effect of condition on calibration, *t* (39) = .05, *p* = .955, CI_{diff} [-.04, .04,], *d* = 0.01.

Overall, exercise prior to encoding had some effect on the accuracy of FOK judgements. Despite a non-significant difference, the moderate effect suggests that exercise prior to encoding motivated a reduced capacity for participants to discriminate between known and unknown items. There is no evidence that exercise prior to encoding had any effect on confidence. Comparison of the means indicates that those in the exercise condition were slightly less overconfident than the control condition.

Table 4

Raw O/U, ANDI and Calibration Values for FOKs per Condition

	ANDI	*O/U*	*C*
	M(SD)	*M(SD)*	*M(SD)*
Exercise (*n* = 21)	.06 (.05)	-.14 (.18)	.11 (.06)
Control (*n* = 20)	.11 (.09)	-.21 (.14)	.11 (.07)

Discussion

The effects of an acute bout of moderate intensity exercise were examined for measures of memory and metamemory accuracy. The findings indicated that an acute bout of moderate intensity exercise wields differential effects on memory and metamemory accuracy. The first hypothesis that exercise prior to encoding would enhance both recall and recognition memory was not supported. The mean number of words correctly recalled and recognised did not significantly differ between the two groups.

The present study tested for the effects of exercise on the accuracy of JOL and FOK predictions. Hypotheses of such effects were made based on two competing models. It was predicted that (a) improved memory through exercise would elicit parallel improvements to metamemory accuracy, or (b) exercise prior to making JOLs and FOKs would inflate confidence, thus reducing metamemory accuracy. The data indicated that exercise prior to encoding diminished the capacity for JOLs to distinguish between known and unknown items. It also indicated that those who exercised prior to studying had greater overconfidence in their recall ability. Conversely, the data indicated no effects of exercise on FOK accuracy for participants' confidence. There was however a trend towards exercise having a detrimental effect on FOK ability to discriminate between remembered and forgotten items.

Exercise and Memory

There is both theoretical and empirical evidence to suggest that exercise improves memory (Labban & Etnier, 2011; Chang et al., 2012). Studies utilising the exercise protocols in line with literature recommendations regarding intensity and duration tend to produce large magnitude effects on long-term retention (Labban & Etnier, 2011; Stefanidis et al., 2016). However, despite utilising an exercise protocol based on these recommendation, the results do not support arguments of enhancement of memory. Inconsistent with previous research (Labban & Etnier, 2011; Stefanidis et al., 2016), comparison of the means suggests a trend towards exercise reducing recall performance, however, the difference between groups was non-significant.

Despite the evidence that a single session of moderate intensity exercise prior to encoding enhances memory, other research using paired-associate learning paradigms has challenged these findings. For example, Tomporowski, Ellis, and Stephens (1987) were unsuccessful in observing effects of treadmill running on free recall. Similarly, McNerney and Radvansky (2015) observed no effects of increased memory succeeding paired-associate learning for exercise conditions. They argued that exercise prior to learning may not be beneficial for consolidation of all types of memory, dependent upon the learning task. For example, Winter et al. (2007) observed improvements to memory following a paired-associate learning task, where novel words were paired with object images, increasing the likelihood of meaningful encoding. However, like McNerney and Radvansky, the present study used word pairs which were not meaningfully associated, thus reducing any opportunity for meaningful encoding. McNerney and Radvansky argued that exercise may be beneficial for memory when meaning and comprehension are factors enhancing learning, but not beneficial when paired associates do not have this inherent meaning (McNerney & Radvansky, 2015). The present data support this argument that exercise may be detrimental when forming memories during paired-associate learning tasks.

Metamemory

The present data provides further evidence regarding the accuracy of both JOLs and FOKs. Regardless of condition, participants had some capacity for predicting the accuracy of their memory and discriminating between remembered versus forgotten items.

Research has suggested that recall and metamemory accuracy may be sensitive to the amount of to-be-remembered information presented (Tauber & Rhodes, 2010). When the number of to-be-remembered items is higher (e.g., 100 word lists), individuals have reduced confidence in their ability for recall (i.e., smaller JOL magnitude). However, given that attempting to learn more items serves to reduce memory accuracy, overconfidence can become an issue when there is more to-be-remembered information. When reduced memory performance outweighs reduced confidence (i.e., memory performance is lower in comparison to confidence ratings), there is a tendency for overconfidence because individuals are not adjusting their confidence accordingly given their poorer recall performance (Tauber & Rhodes, 2010). The present study suggests that overall, individuals had a diminished capacity for adjusting their confidence in their ability relative to their actual recall performance, thus indicating overconfidence.

Exercise and JOLs. The present data provides two novel findings regarding the effects of acute exercise on JOLs. First, exercise prior to encoding had a detrimental effect on participants' ability to discriminate between items remembered versus items forgotten. Discrimination, as indexed via *ANDI* values, significantly differed between the exercise and control condition. Direct access models argue that memory capacity is likely to influence one's ability to discriminate between items they do and do not remember (Schwartz et al., 1997). Thus, those with better memory will have a greater ability for discriminating between items they do and do not know. Alternatively, those who have a poorer memorial representation will have a reduced capacity for discrimination. In terms of recall performance, whilst the difference between the groups was non-significant, the direction of the means suggests that those who exercised prior to encoding had poorer memory. Upon examination of the *ANDI* values, the control condition had a value closer to one (i.e., had better resolution and thus more ability to discriminate between items they did and did not remember). These findings suggest that exercise prior to encoding decreased effective memorial representation of the material (however, not significantly so), which may explain why they were worse at discriminating between remembered and forgotten items.

Second, exercise prior to encoding exerted an effect on overall confidence in recall ability. Those who exercised prior to encoding demonstrated greater overconfidence in their performance compared to their actual recall accuracy. Although the differences were non-significant, the exercise condition recalled less words and had higher magnitude JOLs. Thus, because memory did not improve but JOLs were increased, overconfidence was greater. If the monitoring of memory was effective, individuals would be able to adjust their confidence ratings to match their actual recall performance through attempted retrieval. However, ineffective monitoring influencing overconfidence suggests that individuals who exercised prior to encoding may be relying on other cues to inform their confidence, rather than a retrieval attempt.

Recall that Salas et al. (2011) observed effects of walking prior to encoding on recall memory performance and absolute metamemory accuracy (those who exercised were less overconfident). However, because the magnitude of JOLs did not differ across conditions, they suggested that improvements to absolute metamemory accuracy were a function of improvements in recall. Thus, walking did not actually improve metamemory accuracy, but it enhanced memory and participants did not effectively monitor their memory and evaluate their JOLs according to this memory improvement (Salas et al., 2011). Therefore, because memory increased but JOLs were not corrected to take this into account, overconfidence was reduced (Salas et al., 2011).

These null effects on metamemory accuracy and confidence found by Salas et al. (2011) may be because participants did not have previous knowledge about using exercise to enhance memory. Understanding how your memory works and factors that enhance memory is an important constituent of metamemory, particularly for monitoring and evaluating whether a learning method is effective or not. Forming such an understanding can be information-based, where individuals rely on the information and knowledge they can retrieve from their memory; or it can be experience-based, in which individuals rely on their subjective experience to make judgements about the efficacy of their learning (Koriat, 2000). However, if individuals rely solely on their subjective experience, the accuracy of their predictions can be contaminated by irrelevant factors, thus reducing accuracy (Nussinson & Koriat, 2008).

When making JOLs, individuals can rely on a priori beliefs to inform predictions, such as beliefs about the ease of learning as a representation of their ability for retrieval (Souchay, Isingrini, Clarys, Taconnat, & Eustache, 2004). If someone has a knowledge base that exercise can improve memory, they may use this to inform a belief that exercise prior to studying will augment memory performance. Subsequently, this may contribute to judgements of higher confidence in their ability to recall the material, whereby if they think they will have better memory for that material, they will have greater confidence in their ability to recall it on a test. This process may work in both a conscious (i.e., an individual has this conscious belief that their memory will be improved) and unconscious manner (i.e., the physiological mechanisms associated with exercise give feelings of greater attention and concentration which may unconsciously inform perceived ease of encoding).

However, given that the present study has suggested that exercise does not enhance long-term memory, such beliefs are likely to contaminate predictions about future recall. For example, those who exercised prior to encoding may have had the impression that they would remember the items better, based on an a priori belief that exercise is beneficial for memory. Additionally, if individuals are unaware that their subjective beliefs are biased (i.e., ineffective monitoring of memory), thus rendering it an unreliable basis for memory judgements, they are unlikely to make corrections to account for this bias, hence leading to greater overconfidence in their recall ability (Souchay et al., 2004).

Exercise and FOKs. Being the first study to directly investigate the effects of a single session of exercise on FOK judgements, the present data contributes two novel findings to the literature. First, there was no significant effect of exercise on resolution. FOK discrimination ability did not differ between the two groups. A comparison of the means indicated that the control condition was slightly better at discriminating between items they did and did not remember. However, a non-significant result is not conclusive in saying that there is no difference, merely that the present study has been unable to identify such a difference (Matthews & Altman, 1996). Additionally, findings are more likely to be true in scientific research when effects are large (Ioannidis, 2005). Thus, the findings whilst ambiguous with a non-significant difference with a moderate to large effect, may be a by-product of an under powered study due to a small sample size (Ioannidis, 2005). Given the moderate to large effect, differences in resolution between groups is likely to be true and thus will be interpreted as such.

Previous research has argued that the quality of the original encoding conditions plays a role in FOK resolution (Hertzog, Dunlosky, & Sinclair, 2010; Sacher, Taconnat, Souchay, & Isingrini, 2009). These studies argue that conditions which increase encoding quality will subsequently increase FOK resolution. Thus, better encoding (i.e., better memory performance) will encourage greater FOK accuracy. Most exercise and memory research argues that exercise prior to encoding enhances cognitive resources, thus enhancing the quality of the encoding conditions (Brisswalter et al., 2002). However, the present study was unsuccessful in replicating these findings, as those who exercised prior to encoding did not have superior memory performance. Despite no significant difference in recognition performance, comparison of the means suggests a trend towards the exercise condition having reduced recognition. This may suggest that exercise prior to studying may be reducing the quality of the encoding condition, whether that be via conscious or unconscious processes (e.g., stress hormones causing decreases in consolidation ability; Diamond et al., 2006; Maroun & Akirav, 2007). However, the interpretation of this relationship is tentative and should not be overstated, given the non-significant result.

The second novel finding was the null effect of exercise on confidence. Confidence, as indexed by *O/U* values, did not differ significantly between the experimental conditions. Both conditions had negatively weighted bias scores, indicating some level of underconfidence in their recognition ability. Underconfidence indicates that participants gave lower FOK ratings in comparison to their actual recognition performance. This finding may suggest the use of partial information relating to the target to guide their judgements (Koriat, 2007). For example, a considerable number of participants failed to give responses to a substantial amount of items during the recall test. Providing no answers is suggestive of poorer memorial representation. Having partial information about the cue word (e.g., "I was unable to recall this word therefore I don't know the correct answer) may guide participants FOK judgements about their capacity for future recognition

(Koriat, 2007). This would indicate greater metacognitive monitoring, to be able to use such cues to adjust their FOK predictions for future recall. However, the present results suggest that whilst participants may have used such information, reliance on this information has influenced maladaptive adjustments to their FOKs which was not reflective of their recognition performance.

Theoretical Implications

The findings from the present study indicate differential effects of moderate intensity exercise on memory and metamemory. Specifically, exercise prior to encoding does not improve recall or recognition memory performance, but it does have effects on the ability to discriminate between remembered versus forgotten items and on confidence. These findings align more so with an inferential approach to metamemory, which argues that individuals rely on various cues to guide their judgements about the adequacy of their memory (Koriat, 1997; Koriat & Ma'ayan, 2005). The accuracy of metamemory judgements is dependent upon the validity of these cues (Koriat, 1997). For example, using extrinsic cues relating to the subjective experience of the learning situation is likely to undermine metamemory accuracy. In the context of the present study, such cues could include individual beliefs about how exercise influences memory or subjective judgements about perceived encoding or retrieval fluency caused by exercise-induced arousal. Consequently, the use of such cues by participants has influenced a reduction in metamemory accuracy, however the basis of such cues requires further examination.

Practical Implications

The findings from the present study suggest clear implications for applied settings, such as educational contexts. The present findings are inconsistent with previous research, which suggest that exercise prior to study would be beneficial for student learning (e.g., Labban & Etnier, 2011; Stefanidis et al., 2016). Instead, they suggest that exercise prior to studying may be detrimental to learning and memory. In particular, these results indicate that exercising prior to paired associate learning influences reduced memory capacity for later retrieval. For example, individuals trying to learn a new language through paired-associate learning may not benefit from exercising prior to studying. These results are not generalizable to other learning tasks, thus research should continue to investigate how exercise influences different learning and memory types. Educational settings are also likely to have longer retention intervals (e.g., learning new material and being tested on it a week or two later). Thus the results from the present study are not generalizable to such conditions given the 20-minute retention interval used. Research has indicated that longer retention intervals improve memory by facilitating the effective transfer of encoded information into long-term memory (Roig et al., 2013). However, in an educational context where material is likely to be studied more than once, practice effects may also be of interest. This provides a gap for further research to examine whether exercise continues to have a detrimental effect on memory following longer retention intervals, or if a longer retention interval modulates any negative effects of exercise on memory.

Limitations

The nature of the exercise, encoding and testing conditions may serve as a limitation of the present study. Such conditions are likely to undermine the ecological validity of the results observed, particularly for applied settings where exercise intensity, duration and retention intervals differ. Research has argued that there are optimal exercise conditions to enhance memory, whereas manipulation of such conditions will undermine memory performance. The most noted optimal condition is exercise of moderate intensity, where physical exertion of higher intensities has been shown to undermine memory performance (Hope et al., 2012). Whilst the present study utilised an exercise protocol of moderate intensity, it was unsuccessful in finding effects on memory to corroborate previous research (Labban & Etnier, 2011; Stefanidis et al., 2016). However, it did present substantiating evidence for the arguments made by researchers such as McNerney and Radvansky (2015), who argued that memory for paired-associates may be diminished if one engages in exercise prior to learning. However, the differences in recall performance were not significant, which may suggest that the small sample size has undermined the power of the study. Thus, future research should utilise larger sample sizes to further investigate these arguments surrounding the effect of exercise on memory following paired-associate learning.

The methodology of the current study could have also undermined the ability to detect effects of exercise on FOK judgements and recognition performance. Numerous researchers have argued that the effects of exercise span for a specific period of time before they begin to gradually decline (Chang et al., 2012). Given the lengthy process from the end of the exercise bout to the point of providing FOKs and completing the recognition test, the physiological mechanisms activated via exercise-induced arousal are likely to have depleted back to normal levels. The depletion of these biological markers would suggest that exercise is no longer having a positive effect on memory, which may explain why the present data indicates null effects on recognition memory. However, such interpretations are speculative given that the time-course of biological mechanisms to modulate memory formation is relatively unknown (Molteni, Ying, & Gomez-Pinilla, 2002). Future research should continue to investigate possible effects of moderate intensity exercise on FOK predictions and recognition memory with greater consideration of time constraints on exercise effects.

Conclusion

In conclusion, the results from the present study suggest that exercise has differential effects on memory and metamemory. Exercise prior to studying reduced memory performance for both recall and recognition tests. It also reduced the accuracy of all measures of JOL accuracy. Specifically, exercise prior to encoding diminished the capacity for JOLs to distinguish between known and unknown items and it inflated confidence to a level of significant overconfidence, thus causing deviation from optimal calibration. Exercise prior to encoding also decreased the capacity for FOKs to discriminate between known and unknown items, however, there were no effects of exercise on confidence. These results suggest that physical activity may be problematic in applied settings such as educational contexts, as exercising prior to studying may not only decrease memory for the learnt material, but it may also reduce the accuracy of judgements made about one’s memory (i.e., inflating confidence in one’s memory).

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Appendix A – Ethics Approval Letter

Inbox

-----Original Message-----
From: Lauren.Black@utas.edu.au [mailto:Lauren.Black@utas.edu.au]
Sent: Tuesday, 12 July 2016 15:07
To: Matt Palmer
Cc: Peter Tranent; Kayla Stefanidis; Lauren Black
Subject: Notification of Amendment Approval: H0014950 The Effects of Exercise on Memory

Dear Dr Palmer

Ethics Ref: H0014950
Title: The Effects of Exercise on Memory

This email is to confirm that the following amendment was approved by the Chair of the Tasmania Health and Medical Human Research Ethics Committee on 12/7/2016:

Amendment Change in CI from Mr P Tranent to Dr M Palmer Protocol Addition of two investigators: A Turner and F Parkes

All committees operating under the Human Research Ethics Committee (Tasmania) Network are registered and required to comply with the National Statement on Ethical Conduct in Human Research (NHMRC 2007).

This email constitutes official approval. If your circumstances require a formal letter of amendment approval, please let us know.

Should you have any queries please do not hesitate to contact me.

Kind regards

Lauren Black

--
Lauren Black
Executive Officer - Ethics
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Appendix B – Information Sheet and Consent Form

Participant number ________________

FACULTY OF HEALTH

PARTICIPANT INFORMATION SHEET

1. Invitation

You are invited to participate in a research study examining the effects of exercise on cognitive function.
This study is being conducted by:

- Dr Matthew Palmer, Supervisor, School of Psychology, UTAS;
- Ashlee Turner, Honours student, School of Psychology, UTAS.

2. What is the purpose of this study?

This study aims to investigate the effects of a single session of exercise on memory and metamemory (judgements of your memory).

3. Why have I been invited to participate?

You are eligible to take part in this study because you are over the age of 18 years and do not have a history of:

- Cardiovascular disease
- Hypertension
- Uncontrolled diabetes
- Physical injuries
- Cognitive or learning impairments

4. What will I be asked to do?

Firstly, you will be asked to complete a health and medical questionnaire and a physical activity questionnaire. These will ask for information regarding your medical history, level of physical activity, body mass index (BMI), and daily tobacco, alcohol and caffeine intake.

You will be asked complete one of two conditions: exercise before learning, or no exercise. The exercise period will involve a 5-minute warm-up, 20-minutes of moderate intensity exercise, and a 5-minute cool down, all completed on a stationary bike. You will also be asked to rate your level of physical exertion every 5-minutes.

This study involves:

- Wearing a heart rate monitor
- You will be asked to study word items as quickly as possible for a memory test
- You will be asked some questions about your memory for those items

We expect the total session to take approximately 1.5-2 hours to complete.

5. Are there any possible benefits from participation in this study?

We do not expect direct benefits for participants in this study. However, this study will advance our knowledge of the effects of exercise on judgements of metamemory, and the results may help shape recommendations (e.g., for students exercising during study periods).

Participant number _______________

6. Are there any possible risks from participation in this study?

The main risks are those associated with undertaking moderate intensity exercise. If you experience dizziness, fatigue, pain, injury or illness during the session you will be immediately withdrawn from the study and referred to a medical practitioner.

7. What if I change my mind during or after the study?

You are free to withdraw at any time, and can do so without providing an explanation. However, if you choose to withdrawal after the study, it will not be possible to remove your data, as it will be stored anonymously.

8. What will happen to the information when this study is over?

Data will be non-identifiable. It will be stored on an online server for five years from the date of thesis completion. This server is password-protected and only accessible to the researchers of this study. Data will be destroyed following this period, unless you agree to have your data archived.

9. How will the results of the study be published?

All data in this study will be anonymous. Data from this study will be discussed and may be published. If you wish to be notified on the results of this study, please feel free to contact us.

10. What if I have questions about this study?

If you have any queries, concerns or issues with this study, please feel free to contact us:

- Dr Matthew Palmer, Matthew.Palmer@utas.edu.au
- Ashlee Turner, ashleet@utas.edu.au

This study has been approved by the Tasmanian Health and Medical Human Research Ethics Committee. If you have concerns of complaints about the conduct of this study you should contact the Executive Officer of the HREC (Tasmania) Network on (03) 6226 6254 or email human.ethics@utas.edu.au. The Executive Officer is the person nominate to receive complaints from research participants. You will need to quote [H0014950]

Thank you for your time.

CONSENT FORM
Exercise and Memory

1. I agree to take part in this research study.
2. I have read and understood the Information Sheet for this study.
3. The nature and possible effects of the study have been explained to me.
4. I understand that the study involves:
   - Providing information regarding my medical history, level of physical activity, Body Mass Index (BMI), tobacco, alcohol and caffeine intake.
   - My heart rate will be monitored
   - I may be asked to do a 5-minute warm up, 20-minutes of moderate intensity exercise, and a 5-minute cool down on a stationary bike
   - I will be asked to study word items for a memory test
   - I will be asked to watch a short film for 30-minutes
5. I understand that participation involves the risks associated with undertaking moderate intensity exercise.
6. I understand that all research data will be securely stored on a password-secured database for five years from the publication of the study results, and will then be destroyed unless I give permission for my data to be stored in an archive.
   I agree to have my study data archived.

   Yes ☐ No ☐
7. Any questions that I have asked have been answered to my satisfaction.
8. I understand that the researchers will maintain confidentiality and that any information I supply to the researchers will be used only for the purposes of the research.
9. I understand that the results of the study will be published so that I cannot be identified as a participant.
10. I understand that my participation is voluntary and that I may withdraw at any time without any effect.
11. I understand that I will not be able to withdraw my data after completing the study, as it will be stored anonymously.

Participant's name: ____

Participant's signature: ____

Date: ____________________

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Statement by Investigator

☐ I have explained the project and the implications of participation in it to this volunteer and I believe that the consent is informed and that he/she understands the implications of participation.

If the Investigator has not had an opportunity to talk to participants prior to them participating, the following must be ticked.

☐ The participant has received the Information Sheet where my details have been provided so participants have had the opportunity to contact me prior to consenting to participate in this project.

Investigator's name: ____

Investigator's signature: ____

Date: ________________________

Appendix C – Memory Test

CUE	TARGET	RECOGNITION TEST			
Alert	Polka	Whack	Lorry	Polka	Nymph
Algae	Demon	Demon	Sneer	Flock	Quack
Armour	Volume	Speech	Volume	Needle	Blouse
Atom	Lust	Duke	Feer	Chop	Lust
Bank	Oven	Sign	Plug	Cube	Oven
Banner	Kettle	Tunnel	Shadow	Kettle	Degree
Basin	Wheat	Wheat	Right	Anger	Sleep
Bass	Dive	Dive	Itch	Lung	Hint
Battle	School	Market	Carpet	Sneeze	School
Bean	Trim	Trim	Cage	Loot	Dart
Beast	Offal	Chasm	Adage	Frock	Offal
Bucket	Parade	Throat	Parade	Locker	Diving
Buckle	Lichen	Quiver	Colony	Lichen	Frenzy
Buffer	Nutmeg	Nutmeg	Manure	Icicle	Ginger
Camera	Stable	Phrase	Worker	Stable	Puddle
Canal	Dryad	Noman	Dryad	Baron	Pique
Cent	Foil	Rent	Foil	Diet	Gang
Choir	Pupil	Light	Pupil	Essay	Steel
Circle	Muscle	Nickel	Branch	Muscle	Gravel
Clasp	Berry	Wound	Quilt	Berry	Drill
Cloud	Ivory	Adult	Laugh	Ivory	Spoon
Comedy	Walrus	Strain	Walrus	Grover	Length
Dancer	Magnet	Magnet	Weapon	Banker	Sleeve
Debut	Stoic	Tally	Borne	Stoic	Abhor
Decoy	Stalk	Spook	Stalk	Brute	Rhyme
Diadem	Scroll	Plaice	Morass	Scroll	Foible
Dome	Cape	Lock	Scab	Cape	Dust
Drain	Cliff	Water	Slush	Cliff	Sting
Edict	Flare	Agony	Rough	Skirt	Flare
Equity	Breeze	Breeze	Insult	Minute	Hunger
Fang	Clue	Drum	Clue	Myth	Cost
Fruit	Lathe	Sonata	Wicket	Keel	Lathe
Glass	Petal	Coral	Witch	Petal	Tunic
Goblet	Carrot	Murder	Garlic	Carrot	Period
Gold	Club	Club	Foot	Rail	Town
Grind	Brawl	Shear	Derby	Brawl	Whiff
Hail	Axle	Stub	Axle	Vine	Crab
Horn	Echo	Brim	Echo	Omen	Crowd
Hotel	Brain	Stool	Spark	Chart	Brain

Hound	Abode	Abode	Wharf	Thyme	Flora
House	Penny	Water	Shirt	Radio	Penny
Hurdle	Feline	Feline	Urchin	Squire	Pestle
Ivory	Plane	Cheek	Metal	Stair	Plane
Juice	Pearl	Human	Pearl	Chain	Toast
Lady	Pick	Suit	Wind	Case	Pick
Lilly	Area	Swim	Area	Gown	Bark
Liquid	Soccer	Ticket	Candle	Soccer	Avenue
Malady	Belfry	Wigwam	Belfry	Frieze	Gullet
Mast	Kale	Lynx	Flue	Kale	Gilt
Mince	Birth	Reach	Ounce	Scale	Birth
Mite	Seed	Seed	Deck	Bill	Heel
Mutton	Bandit	Estate	Plunge	Savoury	Bandit
Newt	Film	Rope	Film	Pork	Loss
Noodle	Lotion	Rumble	Sketch	Lotion	Muzzle
Novel	Storm	Wheel	Rusty	Trash	Storm
Orchid	Cornet	Tailor	Shield	Prison	Cornet
Organ	Noose	Belle	Noose	Abyss	Deity
Oxygen	Beauty	System	Heroin	Beauty	Hazard
Paint	Cabin	Cabin	Earth	Brush	Uncle
Parcel	String	Ground	String	Umpire	Poison
Pastor	Bronze	Mallet	Bronze	Anchor	Terror
Phone	Empty	Voter	Sight	Empty	Guest
Poet	Blue	Blue	Mold	Beer	Lamp
Rash	Text	Text	Leak	Cold	Knob
Realm	Apray	Taper	Apray	Proxy	Liken
Rebel	Whirl	Spout	Whirl	Swarm	Corps
Ribbon	Caucus	Encore	Nectar	Caucus	Sultan
Rice	Cyst	Bard	Cist	Dolt	Font
Rifle	Knoll	Knoll	Alien	Dough	Prune
Rubber	Engine	Engine	Silver	Breast	Velvet
Rule	Patch	Stain	Chest	Level	Patch
Saga	Ruff	Pare	Zeal	Glut	Ruff
Salve	Arbour	Maize	Polyp	Phial	Arbour
Scotch	Corner	Monkey	Corner	Bleach	Singer
Seer	Pipe	Wool	News	Dime	Pipe
Sever	Quake	Quake	Liter	Spasm	Craft
Shovel	Brandy	Pocket	Insect	Brandy	Closet
Skate	Floor	Floor	Ditch	Judge	Crowd
Smelt	Fable	Donor	Links	Grate	Fable
Sphere	Aurora	Aurora	Ramrod	Mosque	Cuttle
Sponge	Lawyer	Pepper	Yellow	Driver	Lawyer
Stay	Axil	Axil	Trey	Gore	Rick
Stone	Dozen	Dozen	Straw	Glove	Minor

Strop	Badge	Flesh	Trunk	Cable	Badge
Supper	Coffer	Portal	Coffer	Abbess	Tenure
Sword	Cream	Sugar	Dance	Cream	Title
Synod	Paste	Claim	Brick	Lease	Paste
Tape	Soil	Hood	Moon	Soil	Fuel
Teem	Sine	Sine	Ware	Gait	Veto
Temper	Basket	Temper	Violet	Fleece	Basket
Tent	Hawk	Zero	Germ	Hawk	Tear
Thief	Dress	Dress	Graph	Sauce	Purse
Trail	Coast	Slope	Coast	Paste	Aisle
Tribe	Music	Music	Flood	Spice	Cloud
Turtle	Beggar	Cymbal	Stanza	Beggar	Galaxy
Vase	Lute	Mall	Jibe	Cyst	Lute
Whoop	Parry	Aster	Squib	Cleat	Parry
Widow	Delta	Globe	Delta	Suite	Cloak
Wire	Park	Slap	Park	Army	Bowl
Wreck	Board	Board	Motor	Spear	Cross

Appendix D – Exercise Pre-Screen Form

ADULT PRE-EXERCISE SCREENING TOOL

Name: ______
Date of birth: _____
Date: ______

STAGE 1

Please highlight your answer.

1. Has your doctor ever told you that you have a heart condition or have you ever suffered a stroke?

   YES NO

2. Do you ever experience unexplained pains in your chest at rest or during physical activity/exercise?

   YES NO

3. Do you ever feel faint or have spells of dizziness during physical activity/exercise that causes you to lose balance?

   YES NO

4. Have you had an asthma attack requiring immediate medical attention at any time over the last 12 months?

   YES NO

5. If you have diabetes (type I or type II) have you had trouble controlling your blood glucose in the last 3 months?

   YES NO

6. Do you have any diagnosed muscle, bone or joint problems that you have been told could be made worse by participating in physical activity/exercise?

   YES NO

7. Do you have any other medical condition(s) that may make it dangerous for you to participate in physical activity/exercise?

   YES NO

STAGE 2

1. Age: ________
   Gender: _______

2. Family history of heart disease (e.g., stroke, heart attack):
   Relative ________ age of relative__________
   Relative_________ age of relative__________

3. Do you smoke cigarettes on a daily or weekly basis or have you quit smoking in the last 6 months? _________

   a. If currently smoking, how many per day or week? __________

4. Describe your current physical activity/exercise levels:

	SEDENTARY	LIGHT	MODERATE	VIGOROUS
FREQUENCY Sessions per week				
DURATION Minutes per week				

5. Please state your height (cm): _____
   Please state your weight (kg): _____

6. Have you been told that you have high blood pressure?

   YES NO

7. Have you been told that you have high cholesterol?

   YES NO

8. Have you been told that you have high blood sugar?

   YES NO

9. Have you spent time in hospital (including day admission) for any medical condition/illness/injury during the last 12 months?

   YES NO
   If yes, provide details: ____

10. Are you currently taking a prescribed medication(s) for any medical condition(s)?

    YES NO
    If yes, what is the medical condition(s)? ________________________________

11. Are you pregnant or have you given birth within the last 12 months?

    YES NO
    If yes, provide details. I am ___ months pregnant or postnatal (highlight/circle).

12. Do you have any muscle, bone or joint pain or soreness that is made worse by particular types of activity?

    YES NO
    If yes, provide details: ____

I believe that to the best of my knowledge, all of the information I have supplied within this tool is correct.
Signature: Date:

Appendix E – International Physical Activity Questionnaire (I-PAQ)

Please answer the following questions as honestly as possible.

1. What is your current level of education? (e.g., graduated high school, undergraduate, post graduate)

   ………………………………………………....

2. On average, how often do you consume alcohol?

   Never ☐

   Once a month or less ☐

   2-4 times per month ☐

   2-4 times per week ☐

   4 or more times per week ☐

   Daily ☐

3. How often would you consume caffeine per week?

   I don't consume caffeine ☐

   Once per week or less ☐

   1-2 times per week ☐

   1-2 times per day ☐

   3 or more times per day ☐

Think about activities which take **moderate physical effort** that you did in the **last 7 days**. Moderate physical activities make you breathe somewhat harder than normal and may include carrying light loads or bicycling at a regular pace. This does not include walking. Think only about the activities that you did **for at least 10 minutes** at a time.

4. How much time did you usually spend doing **moderate** physical activities on one of those days?

   ______ hours per day

______ **minutes per day**

☐ Don't know/not sure

Think about the time you spent **walking** in the **last 7 days**. This includes at work and at home, walking to travel from place to place, and any other walking that you might do solely for recreation, sport, exercise, or leisure.

5. During the last 7 days, on how many days did you **walk** for at least 10 minutes at a time?

   ______ **days per week**

   ☐ No walking ***Skip to question 7***

6. How much time did you usually spend **walking** on one of those days?

   ______ **hours per day**

   ______ **minutes per day**

   ☐ Don't know/not sure

The last question is about the time you spent **sitting** on weekdays during the **last 7 days**. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading or sitting or lying down to watch television.

7. During the last 7 days, how much time did you spend **sitting** on a **week day**?

   ______ **hours per day**

   ______**minutes per day**

   ☐ Don't know/not sure

Appendix F – SPSS Data Output

Manipulation Check

Group Statistics

	condition	N	Mean	Std. Deviation	Std. Error Mean
resting HR	control	20	72.65	10.879	2.433
	exercise	21	78.86	8.737	1.906
HR start study	control	20	73.35	12.097	2.705
	exercise	21	113.14	13.883	3.029
HR end study	control	20	74.05	11.799	2.638
	exercise	21	88.29	12.630	2.756

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
resting HR	Equal variances assumed	.761	.388	-2.019	39	.050	-6.207	3.074	-12.425	.011
	Equal variances not assumed			-2.008	36.447	.052	-6.207	3.091	-12.473	.058
HR start study	Equal variances assumed	.088	.769	-9.764	39	.000	-39.793	4.075	-48.036	-31.550
	Equal variances not assumed			-9.798	38.706	.000	-39.793	4.061	-48.010	-31.576
HR end study	Equal variances assumed	.306	.584	-3.725	39	.001	-14.236	3.822	-21.966	-6.505
	Equal variances not assumed			-3.731	38.987	.001	-14.236	3.815	-21.953	-6.519

Possible Moderating Factors

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	3.785[a]	3	.286
Likelihood Ratio	4.950	3	.175
Linear-by-Linear Association	.764	1	.382
N of Valid Cases	41		

a. 4 cells (50.0%) have expected count less than 5. The minimum expected count is 1.46.

Group Statistics

	condition	N	Mean	Std. Deviation	Std. Error Mean
BMI	control	20	22.04	6.443	1.441
	exercise	21	24.13	3.496	.763

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
BMI	Equal variances assumed	1.416	.241	-1.296	39	.203	-2.084	1.608	-5.336	1.169
	Equal variances not assumed			-1.278	28.987	.211	-2.084	1.630	-5.418	1.251

Memory Performance

Group Statistics

	condition	N	Mean	Std. Deviation	Std. Error Mean
TOTAL RECALL ACCURACY	control	20	17.20	18.366	4.107
	exercise	21	11.43	14.945	3.261
TOTAL RECOGNITION ACCURACY	control	20	60.05	18.205	4.071
	exercise	21	54.00	17.352	3.787
FalseRecall	control	20	12.00	11.355	2.539
	exercise	21	18.00	15.947	3.480

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
TOTAL RECALL ACCURACY	Equal variances assumed	1.843	.182	1.106	39	.275	5.771	5.218	-4.782	16.325
	Equal variances not assumed			1.101	36.667	.278	5.771	5.244	-4.858	16.401
TOTAL RECOGNITION ACCURACY	Equal variances assumed	.250	.620	1.090	39	.283	6.050	5.553	-5.182	17.282
	Equal variances not assumed			1.088	38.630	.283	6.050	5.560	-5.199	17.299
FalseRecall	Equal variances assumed	.504	.482	-1.381	39	.175	-6.000	4.343	-14.785	2.785
	Equal variances not assumed			-1.393	36.173	.172	-6.000	4.308	-14.735	2.735

JOL Accuracy

Group Statistics

	condition	N	Mean	Std. Deviation	Std. Error Mean
meanJOL	control	20	27.86500	18.742746	4.191006
	exercise	21	31.78286	18.509147	4.039027
ANDI	control	15	.67653	.184879	.047736
	exercise	20	.40825	.296959	.066402
Cstat	control	20	.05375	.060108	.013440
	exercise	21	.12429	.105645	.023054
OUstat	control	20	.10055	.106192	.023745
	exercise	21	.20005	.151037	.032959

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
meanJOL	Equal variances assumed	.045	.832	-.673	39	.505	-3.917857	5.818678	-15.687245	7.851530
	Equal variances not assumed			-.673	38.848	.505	-3.917857	5.820504	-15.692412	7.856698
ANDI	Equal variances assumed	6.269	.017	3.074	33	.004	.268283	.087265	.090740	.445826
	Equal variances not assumed			3.281	32.084	.003	.268283	.081780	.101721	.434846
Cstat	Equal variances assumed	6.085	.018	-2.610	39	.013	-.070536	.027029	-.125206	-.015865
	Equal variances not assumed			-2.643	32.013	.013	-.070536	.026686	-.124892	-.016180
OUstat	Equal variances assumed	4.826	.034	-2.429	39	.020	-.099498	.040967	-.182361	-.016634
	Equal variances not assumed			-2.449	35.954	.019	-.099498	.040622	-.181886	-.017109

FOK Accuracy

Group Statistics

	condition	N	Mean	Std. Deviation	Std. Error Mean
meanFOK	control	20	38.38300	20.176810	4.511672
	exercise	21	40.09571	21.145273	4.614277
FOKANDI	control	20	.10523	.089821	.020085
	exercise	21	.06365	.048280	.010536
FOKCstat	control	20	.10693	.066635	.014900
	exercise	21	.10604	.060576	.013219
FOKOUstat	control	20	-.20700	.136717	.030571
	exercise	21	-.14762	.179321	.039131

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
									95% Confidence Interval of the Difference	
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
meanFOK	Equal variances assumed	.166	.686	-.265	39	.792	-1.712714	6.460995	-14.781311	11.355882
	Equal variances not assumed			-.265	39.000	.792	-1.712714	6.453428	-14.766009	11.340580
FOKANDI	Equal variances assumed	5.084	.030	1.858	39	.071	.041573	.022369	-.003673	.086819
	Equal variances not assumed			1.833	28.822	.077	.041573	.022680	-.004826	.087971
FOKCstat	Equal variances assumed	.021	.887	.045	39	.965	.000887	.019871	-.039307	.041080
	Equal variances not assumed			.045	38.199	.965	.000887	.019919	-.039429	.041203
FOKOUstat	Equal variances assumed	2.799	.102	-1.188	39	.242	-.059381	.049987	-.160489	.041727
	Equal variances not assumed			-1.196	37.255	.239	-.059381	.049657	-.159972	.041210